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REVIEW ARTICLE

Indian Remote Sensing Sensor System: Current and Future Perspective

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Abstract Over last four decades, a vibrant Remote Sensing programme has seen the development of space-based and airborne remote sensing sensor systems for various science and application studies. The Indian Space Programme, is applications driven with major objective towards national development. A series of earth observation systems have been launched in both polar and geo synchronous orbits starting from Bhaskara, the first experimental Earth Observation satellite in 1979 to Cartosat-2S successfully launched in 2017. A large number of active and passive sensors are observing in optical and microwave spectral regions, providing valuable data at different spatial resolutions for land ocean and atmospheric applications, as per application requirements. Satellite Observations during natural and human-induced hazards have become crucial for protecting the global environment, reducing disaster losses, and achieving sustainable development. Today, India has the world's largest constellation of remote sensing satellites in operation which is being extensively used for resource management and integrated planning for national development. The paper discusses the evolution and functioning of both Optical and Microwave Earth Observations Remote Sensing Sensors developed in India.

Keywords Earth Observation · Agriculture · Biodiversity · Disaster Management · Capacity Building and GEOSS · SAMIR · SLAR · ASAR · DMSAR · RISAT

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1 Introduction

The Earth Observation (EO) satellites play a significant role in providing information in a spatial format and in determining, enhancing and monitoring the overall capacity of the earth. Satellite Observations over land, oceans, atmosphere, and during natural and human-induced hazards have become crucial for protecting the global environment, reducing disaster losses, and achieving sustainable development. Hence Earth Observation from Space has proved to be a game changer in providing valuable information on natural resources and environment at different scales. Indian Space Research Organization (ISRO), has made its mark in all facets of remote sensing and arguably has the most vibrant program, when it comes to civilian usage and outreach in general. Microwave and Electro Optical Remote Sensing programme has taken a great leap through development of remote sensing systems for both space-based and airborne remote sensing activity of ISRO. Today, India has the world's largest constellation of electro optical remote sensing spaceborne systems in operation. Passive Microwave sensors developed at ISRO are aimed at providing atmospheric and oceanographic remote sensing data from space-based platforms. Active Microwave sensors are dedicated to imaging as well oceanographic applications. Imaging sensors, which witnessed a beginning in airborne application, have, over the period, graduated to space borne platforms. Indian Remote Sensing sensors provide space-based remote sensing data in a variety of spatial, spectral and temporal resolution meeting the needs of many applications of relevance to national development. The Indian earth observation satellites specifically designed to meet country's needs can ideally meet the global needs as well, in view of the similarity of situations in India and most parts of the

developing world. This paper takes the reader through various phases of Indian Remote Sensing Sensors developed at ISRO by describing each sensor along with its functioning.

2 Indian Earth Observation Programme

The Indian Earth Observation (EO) Programme started with the experiment on detection of coconut root wilt disease from a helicopter-mounted multi-spectral camera system in 1970 has matured into a fully operational programme. It is self-reliant in every aspect of the technology and applications. It consists of space segment, ground segment, applications programme with particular emphasis on capacity building. The space segment deals with indigenous development of various types of sensors, spacecraft platforms and satellite launch vehicles. Setting up telemetry, tracking and command network of stations, data reception systems and generation of data products are important component of ground segment. Development of algorithms for retrieval of geophysical parameters and related utilization application are carried out for each satellite mission.

Indian EO program started from Bhaskara-1 satellite (June 1979) which had two types of sensor systems viz. television camera and microwave radiometer. Imageries of Bhaskara at 1 km spatial resolution helped in carrying out land use, forestry and geological studies. SAMIR payload measured brightness temperature in 19 GHz and 22 GHz for study of ocean-state, water vapor, liquid water content in the atmosphere, etc. Bhaskara-1 was followed by Bhaskara-2 (Nov. 1981) with improved SAMIR instrument. The first operational remote sensing satellite IRS-1A launched on March 17, 1988 had two types of payloads with Linear Imaging Self Scanned imaging (LISS-1 and LISS-II). IRS-1A mission was followed by IRS-1B and subsequently IRS-P2, IRS-1C, IRS-1D were flown with improvement as per user needs and requirements. Details on evolution of these sensor systems are available in reviews of Navalgund [1], Kasturirangan [2] and Joseph [3]. Currently, thirteen operational satellites are in Sun-synchronous orbit–RESOURCESAT-1, 2, 2A CARTOSAT-1, 2, 2A, 2B, RISAT-1 and 2, OCEANSAT-2, Megha-Tropiques, SARAL and SCATSAT-1, and four in Geostationary orbit- INSAT-3D, Kalpana & INSAT 3A, INSAT -3DR. Varieties of instruments have been flown onboard these satellites to provide necessary data in a diversified spatial, spectral and temporal resolutions to cater to different user requirements in the country and for global usage. The data from these satellites are used for several applications covering agriculture [4, 5], hydrology, urban planning, rural development, mineral prospecting, environment, forestry, ocean resources and disaster management [6].

3 Electro Optical Remote Sensing Sensors

Presently, India is having the world's largest constellation of Electro Optical (EO) remote sensing satellites in operation (Fig. 1). It provides space-based remote sensing data in a variety of spatial, spectral and temporal resolutions, meeting the needs of many applications of relevance to national development. The Indian earth observation satellites specifically designed to meet country's needs is also useful in many global applications [7, 8].

3.1 Resource Monitoring

Resourcesat-1 was launched in 2003 and it changed the way agriculture was monitored and studied in India. The result has been incessant requirement of continuity of service for the series. In April, 2011, Resourcesat-2 was launched followed by Resourcesat-2A in December, 2017. The series has turned out to be one of its kind, having three tier imaging capability with LISS-4 (5.8 m), LISS-3* (23 m), AWiFS-A&B (56 m) (Figs. 2, 3). All the payloads are multispectral with SWIR bands in LISS-3* and AWiFS. This is probably the most widely accepted and popular program among the user community, world over, for its wide ranging applications covering Agriculture, Urban mapping, Forest management etc.

Resourcesat-3 and Resourcesat-3S series of satellites, planned to fly together will be the next big step up. It will retain all the capabilities with enhancement in all aspects of observation. Resourcesat-3 will bring in a set of sensors to cover 925 km swath with a spatial resolution of 20 m in VNIR and SWIR spectrum. This will ensure a revisit in 4 days. Additionally, the satellite also will have capability to observe 280kms from designated altitude with 10 m discriminability. Entire 925 km will also be imaged by a VNIR hyperspectral imager to improve the overall product quality. Resourcesat-3S, with multi-view panchromatic stereoscopic capability having high spatial resolution of 1.25 m will facilitate generation of fused products of great utility.

Designed and developed specifically to meet Meteorological needs, INSAT-3D and 3DR (Fig. 4) together from geostationary orbit, cover the entire Indian landmass and beyond, every 15 min. 1 km in Visible and SWIR bands, and 4kms in Thermal Infrared complement the low earth imaging capability. Geostationary orbit provides constant monitoring and beyond Resourcesat-2A, high repetivity

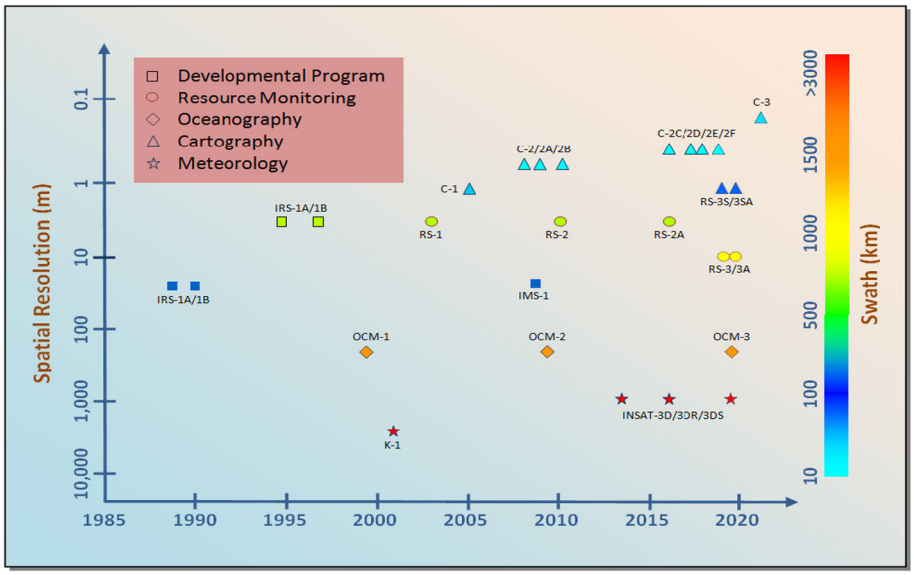

Fig. 1 Electro optical remote sensing program of ISRO

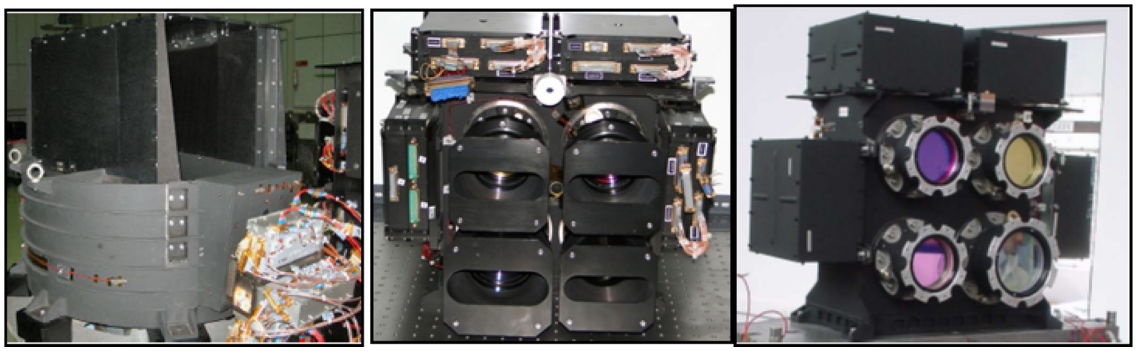

Fig. 2 LISS-4, LISS-3 and AWiFS cameras of resourcesat-2

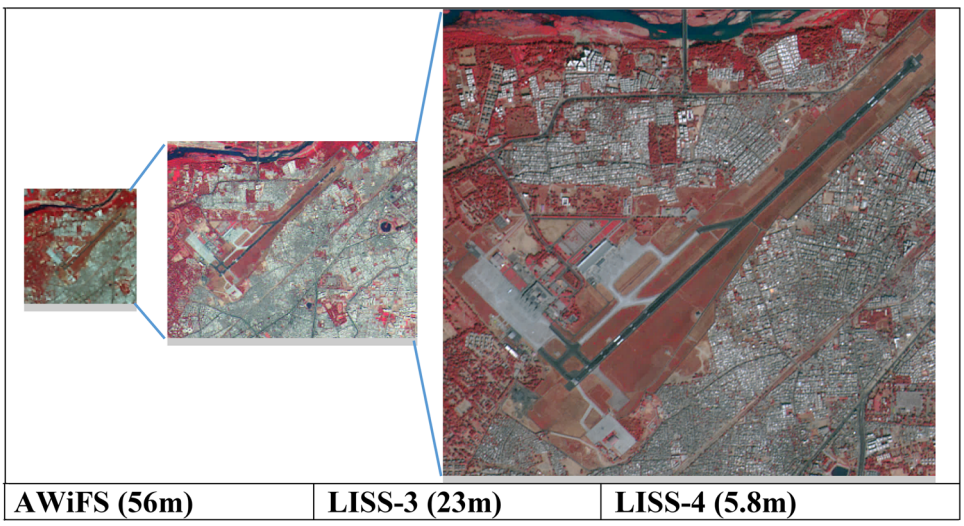

Fig. 3 Three tier imaging by resourcesat-2A, AWiFS (56 m), LISS-3 (23 m), LISS-4 (5.8 m)

sensor would be continued on Geostationary platform as Geo Imaging Satellite (GISAT) mission. This will provide multiple day acquisition capability and shall overcome many limitations posed by AWiFS availability. Since geostationary satellites have longer life, GISAT will assure moderately high spatial resolution (50 m VNIR

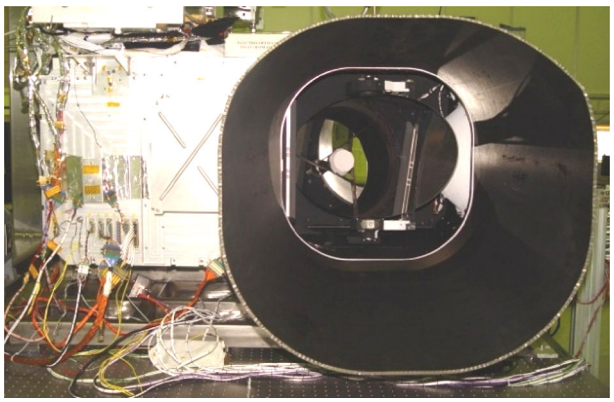

Fig. 4 Imager camera (INSAT-3DR)

Multispectral, 320 m VNIR Hyperspectral, 190 m SWIR Hyperspectral and 1 km TIR) coverage over India for more than a decade.

3.2 Oceanography

Specific attention was given to realize a sensor to meet the requirements related to study of oceans. Oceansat-1 was the first satellite built primarily for ocean applications. It was launched on 26th May, 1999 on-board PSLV-C2. The main mission objective of Oceansat-1 was to gather data for oceanography, land (vegetation dynamics) and atmospheric applications. OCM-1 provided data with two day repetivity, essential for systematic coverage of the huge oceanic resources. The camera aided in determination of chlorophyll concentration, detection and monitoring of phytoplankton blooms and obtain data on atmospheric aerosols and suspended sediments in water.

Continuity in service was ensured with development and launch of follow-on satellite Oceansat-2 on 23rd September, 2009. The OCM-2 payload on board Oceansat-2 satellite is shown in Fig. 5.

Oceansat-3 is planned as next in the series. It will consist of two payloads, OCM-3 having 13 narrow VNIR spectral bands and Sea Surface Temperature Monitor (SSTM-1) having 2 bands in Thermal Infrared region. Configurations for both the payloads have been finalized and the subsystems are in various stages of development.

3.3 High Resolution Observation

Since 1995, with launch of IRS-1C, ISRO has continuously provided High resolution images for various applications like Urban mapping, Cartography and Surveillance. From a spatial resolution of 5.8 m in IRS-1C, the capability has been contnuously improved to 2.5 m in Cartosat-1 to 1 m in Cartosat-2.

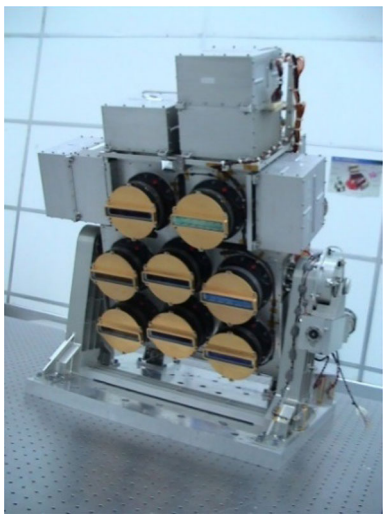

Fig. 5 OCM-2 payload

Presently, Cartosat-2S payload launched in June, 2016 offers spatial resolution of 0.63 m Panchroamtic and 1.57 m VNIR (Fig. 6) multicspectral capability with an operational life of 5 years.

In the field of High resolution imaging, next major jump will be realization of Cartosat-3 series. It will be a highly agile, advanced satellite having imaging capability with a very high spatial resolution of 0.25 m in panchromatic and 1 m in multi spectral bands. The spacecraft platform has many new technologies supporting the mission to manage and handle high data rates, agile enough to obtain more spots and strip images during a pass. This series will also have MWIR imaging capability to meet specific user requirements.

To meet the ever increasing demands, HRSat series will be unique in the sense that it will provide not only high resolution imagery of 1 m, but will also have LWIR channels to cater to day and night monitoring requirements. Moreover, such three satellites will be launched together to offer specific viewing capability. The payload weight in this series will be less than 100 kg.

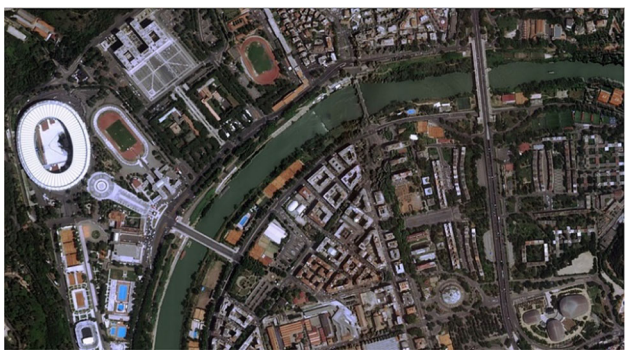

Fig. 6 Cartosat-2S image of rome

3.4 Small Satellite Platforms

ISRO also has taken up experimental missions that are aimed towards demonstration of technologies before they are taken up in regular missions. These missions are undertaken in small satellite platforms to reduce cost, time and associated risks. In order to facilitate systematic development, ISRO has developed standardized spacecraft bus for small satellite platforms. These fall under broad categories of 400 kg class, 100 kg class and 10 kg class of satellites.

In this category, IMS-1 satellite (100 kg class) was launched in 2008. It carried highly miniaturized multi-spectral camera MX-T. It had a four band imaging system that provided performance at par with LISS-2 camera of IRS-1A/1B. The weight of the MX-T camera (Fig. 7) was only 5 kg compared to LISS-2 weight of 150 kg. It also carried a compact imaging spectrometer HySI-T. This instrument provided measurement of reflected spectrum in the visible and near infrared wavelength in 64 contiguous bands. The weight of HySI-T was only 3 kg.

3.5 Airborne Electro Optical Sensors

In addition to providing a wide spectrum of imaging options from space, ISRO has built specific sensors to meet the exclusive requirements of high resolution and hyper-spectral imaging from aerial platform as well. The present suit of sensors comprises multi-view (Fig. 8) panchromatic (ATMC), VNIR multispectral (NMx) and VNIR hyper-spectral (AIMS) instruments. Both panchromatic and multispectral sensor generate imageries with approximately 30 cm spatial resolution from an altitude of 6 km. The hyperspectral sensor offers a spectral resolution of 2.5 nm.

4 Microwave Remote Sensing Sensors

Microwave Remote Sensing (MRS) programme of ISRO has seen the development of both active as well as passive remote sensing systems for space and airborne remote sensing activities [9]. Passive sensors (Radiometers) are aimed at providing atmospheric and oceanographic remote sensing data from space-based platforms, whereas Active sensors (SAR, Scatterometer, Altimeter) are dedicated for land as well oceanographic applications. Synthetic Aperture Radar (SAR) Imaging System, which witnessed a beginning in experimental airborne applications, have, over the period, graduated into operational spaceborne missions. The evolution of MRS programme also resulted into development of various sophisticated key technologies required for this programme.

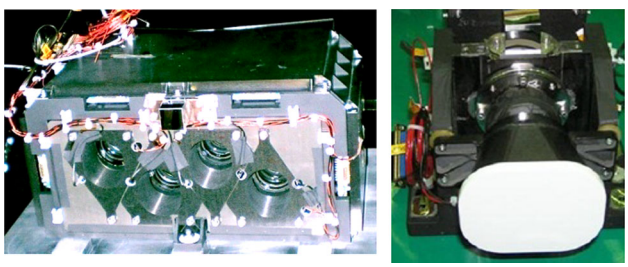

Fig. 7 Mx-T and HySI-T cameras on-board IMS-1

Fig. 8 NMx colour composite

4.1 Atmospheric and Oceanographic Sensors

Both passive and active microwave remote sensing instruments have been/are being developed to meet the requirements of atmospheric and oceanographic applications. From the modest beginning of development of SAMIR payloads for Bhaskara series of satellites for scientific understanding, payloads like MSMR and Scatterometers are designed for providing operational services. At the same time, ISRO initiated collaborative development of payloads, like Megha-Tropiques, with established space agencies, to consolidate expertise available in the development of complex technologies

4.1.1 SAMIR Payload

Satellite Microwave Radiometer (SAMIR) ushered in microwave remote sensing technology. It was flown on Bhaskara-1 and -2 satellites in 1978 and 1981. SAMIR in Bhaskara-1 had 2 channels in 19.35 and 22.35 GHz. SAMIR payload in Bhaskara-2 had additional channel in 31 GHz. SAMIR provided the first glimpse of global water

vapor and liquid water content with indigenous technology. Bhaskara was a spin stabilized satellite and this fact was effectively used to configure this vertically scanning radiometer. This radiometer was configured in Dicke configuration in which scan view of the open sky was used as cold calibration input. It provided a footprint of 150–250 km resolution with sensitivity of 1–2 K. Bhaskara satellites had two spinning modes namely around roll axis or pitch axis. In the first mode of spin, SAMIR provided a swath of 1500 from 777 km altitude. In second mode of spin, in every scan it provided single sample of measurement at Nadir.

4.1.2 MSMR onboard Oceansat-1

Multi-frequency Scanning Microwave Radiometer (MSMR) [10] was the co-passenger payload along with Ocean Colour Monitor (OCM) onboard Oceansat-I (IRS-P4) satellite, ISRO's first satellite dedicated for oceanographic applications. The satellite has been launched on May 26, 1999. MSMR was a four-frequency, dual-polarised scanning microwave radiometer to measure brightness temperatures of the earth surface. This was used for deriving parameters like sea surface temperature, wind speed, water vapour content, etc. from the measured brightness temperatures. The system was designed for four frequencies viz., 6.6, 10.65, 18.0 & 21.0 GHz in order to cater to the above applications.

MSMR provided routinely 48 h global data product, in terms of Brightness Temperature, SST, Wind Speed, Water Vapor content and Cloud Liquid Water, on operational basis from National Remote Sensing Agency (NRSA), Hyderabad, India. The data was used for various experimental investigations like soil moisture, Antarctic ice study etc. Unfortunately, the payload was shutdown after two and half years of operation due to power starvation caused by partial failure of solar panel.

4.2 Ku-band Scatterometer On-Board Oceansat-II

Ku-band Scatterometer was being built by ISRO to gather information about the near surface winds over oceans at a global level. The scatterometer [11] derived ocean surface wind field observations form a very important input to the global weather forecasting system. The scatterometer transmits a pulse through a dual polarized offset reflector antenna, spinning at the rate of 20.5 RPM around yaw axis. The vertical and horizontal beams are pointed at off nadir pointing of 49.4° and 42.6° respectively to cover a total swath of 1800 km with inner beam of 1400 km. All the regions within the inner beam coverage provide azimuthally divergent 4 measurements of radar cross section of capillary waves riding on the gravity waves of the sea. In the inner swath, wind direction can be measured unambiguously. However, in the outer swath, because of availability of only two measurements of radar cross section, wind direction is resolved with the help of auxiliary information like numerical model winds. It operates at 200 Hz, alternate pulses which are switched between V and H ports of the antenna. There is a provision of extensive on-board calibration of the system to provide improved accuracy in wind vector measurements.

OCEANSAT-2 Scatterometer (OSCAT) provided a global coverage of wind vector at 50 kmx50km as well as 25 × 25 km grid every 2 days with most of the earth covering daily. OSCAT proved to be an excellent instrument for oceanography. Widespread acceptance and usage of the OSCAT data by various international agencies like JPL, NOAA, KNMI, EUMETSAT and ECMWF for both research and operational purposes is a testimony to its quality and utility. OSCAT had developed snags in the transmitter subsystem system of primary chain and scan mechanism of the redundant (backup) chain during fag end of its design life period (around 4½ years from launch) forcing the ISRO to suspend its operation in April 2014. Scatterometer on OCEANSAT-2 was followed by dedicated scatterometer onboard SCATSAT-1 Mission in 2016. Various, Hydrological, Agricultural and Forestry applications are being carried out in SCATSAT-1 utilization program. ISRO will be launching OCEANSAT-3 & 3A missions with Ku-band pencil beam scatterometer in 2018/19-time frame.

4.3 Megha-Tropiques

In order to provide boost to climate research with high repetivity data over the tropical regions, a joint Indo-French collaboration resulted in Megha-Tropiques satellite with three payloads, namely

MADRAS (Microwave Analysis And Detection of Rain And Atmospheric Structures)- Imaging microwave radiometer 18.7,23.8, 36.5, 89 to 157 GHz (5 Frequencies and 9 channels); SAPHIR (Sounder for Atmospheric Humidity Profiling (6 Channels around 183 GHz) and SCARAB (Scanner for Radiation Budget)-Broadband radiation measurement instrument in shortwave (< 4 mm) and long-wave (> 4 mm)

MADRAS was configured as total power radiometer with 65 cm diameter antenna to provide observation with resolution from 67 to 10 km over different frequency bands. It provided measurements over a swath of 1700 km at incidence angles ranging from 50°–55°. Megha-Tropiques was placed on an inclined orbit of 20° at 867 km altitude to provide repetitive coverage of equatorial region between 30°N and 30°S at every 6 h.

4.4 Planned MM Wave Sounder

Millimeter wave sounders exploit the atmospheric opacity to sense the atmospheric temperature and humidity profiles. Sounders have an amalgamation of channels at which the atmosphere is opaque for sounding purposes and at which the atmosphere is transparent for correction of the surface contamination. Already a programme to develop MM Wave sounder for measuring vertical profile of atmospheric temperature and humidity has been initiated. Two distinct sounders are being planned: (a) Temperature Sounding Unit (TSU) operating in oxygen absorption band in 50–60 GHz and (b) Humidity Sounding Unit (HSU) operating around 183 GHz. Both these units will operate in vertical scanning configuration.

4.5 Radar Based Imaging Sensors

ISRO mastered space based imaging capability two decades ago with the launch of IRS-1A on 17th March, 1988. Progressively, optical camera based imaging capability is in the path of continuous improvement both in terms of resolution and swath coverage till this date. In a programmatic approach, the scope of ISRO's remote sensing capability was extended to microwave bands after attaining successful grip over imaging technology in optical bands.

Synthetic Aperture Radar (SAR) was logical choice for Imaging Radars in microwave bands, considering its all weather and day-night capability. Further, radar response to geometric shape and distribution of features was realized to be complementary and supplementary to spectral reflectance based feature characterization available in optical imaging process. However, development of SAR needed mastering of both sophisticated radar technology and complex SAR processing algorithm. Since space borne SAR was highly cost intensive, airborne version of SAR was embarked upon as cost effective route of mastering SAR technology in all its nuances. Over the period, both airborne and space borne versions of SAR technology development have taken vibrant shape in ISRO towards harnessing their utilization potential. Summary of Airborne microwave imaging Radars is given in Table 1.

4.5.1 Airborne Imaging Radar Development

4.5.1.1 X-Band Side Looking Airborne Radar (X-SLAR) Imaging Radar development was initiated modestly with development of Side Looking Airborne Radar (SLAR) in X-band. This SLAR was basically used for development of radar technology and it was in flying condition from 1985–1989. SLAR provided imaging over 2–5 km swath with 50 m-100 m resolution. Compared to today's technology, its capability was primitive; but it acted as a test bed to test various new technologies like the radar itself, data recording system and on-board Quick Look Display (QLD) system. Further, the experience gained by experimenting with this system, acted as foundation for subsequent development of complex SAR technology.

ASAR (Airborne SAR) [12–14] was the first proud foray of ISRO in SAR development (Fig. 9). The aim of this development was not only technology attainment but also demonstration of application potential. Consequently, this system was configured in C-band providing 6 m resolution over 25 km swath. Though the breadboard model was tested in 1992, the aircraft was lost in an accident in 1994. The development was continued in a new aircraft and the ASAR system was used for experimentation since 1997.

Table 1 Summary specifications of airborne imaging radars developed in ISRO

	SLAR	ASAR	DMSAR
Frequency	9.6 GHz (X-Band)	5.3 GHz (C-Band)	5.35 GHz (C-Band)
Polarisation	HH	VV/HH	VV/HH
Platform/Altitude	Dakota (2–3 km)	Beechcraft (8 km)	Beechcraft (8 km)
Pulsewidth/Chirp bandwidth	80/300 ns	20 μsec	20 μsec
		25 MHz	22,575
			37.5, 18.75 MHz
Resolution/Swath	50–100 m/5 km	6–8 m/25 km	<2 m/6 km
			3 m/25 km
			5 m/50 km
			10 m/70 km
PRF	850 Hz	425–525 Hz	452 Hz
Peak power	25 kW	2 kW	8 kW
Antenna Length/Pattern	2 m/Cosine Weighted	1.3 m/Cosec^2	1.3 m/Cosec^2

Fig. 9 ASAR system mounted in beechcraft and a sample of imagery obtained by ASAR

For the first time, a modest narrow swath (2.5 km) Real Time Processor was demonstrated in this system.

The high point of this project was development of a sophisticated SAR processor involving motion sensing and compensation. In fact it had a novel two track motion compensation processor which added to the robustness of the system. This algorithm was implemented on a parallel processing system consisting of 8 Xeon processors.

ASAR has been used to demonstrate flood mapping and monitoring operation in 2003–2004. ASAR experience provided the impetus for development of an improved version of C-band airborne SAR, DMSAR (SAR for Disaster Management), exclusively for flood monitoring activity. ASAR experience has demonstrated that for quick reaction to flood related emergency, airborne SAR system is more effective than its space borne counterpart. Spaceborne SARs, with their fixed orbital configuration, cannot ensure quick reaction to flood situation.

4.5.1.2 DMSAR–Airborne SAR for Disaster Management DMSAR was developed with operational requirement for disaster monitoring. To aid flood monitoring and assessment of damage to infrastructure, four resolution modes were provided. DMSAR was test flown for the first time in Nov. 2005. It was calibrated completely and its effectiveness in flood assessment was evaluated in 2006.

To support its high resolution and wide swath capability, the ASAR processing algorithm was significantly modified. A new algorithm called *Track Steering* algorithm was developed (under process of patenting) to process in high resolution modes. The DMSAR processor is available on three platforms:

A parallel machine with 32 Itanium processors; In house developed portable Near Real Time Processor (NRTP) built around 96 TS-101 processors and *GARUDA* computing grid provided by CDAC.

Using this grid, DMSAR data can be processed simultaneously on an array of computing nodes available in academic and research institutions across India. Figure 10 shows the photograph of DMSAR in operation and also a sample of high resolution imagery obtained by it. Figure 10 depicts a typical flood region, mapped by DMSAR, over Dharbhanga, Bihar in 2007. Devastating breach of Koshi River in Nepal in September 2008 as captured by DMSAR is also seen in the Fig. 10. This breach resulted in change of Koshi river track leading to devastating flood of Bihar Plains.

4.5.2 RISAT–Radar Imaging Satellite, ISRO's First SAR Satellite

India's first C-band spaceborne SAR onboard Radar Imaging Satellite-1 (RISAT-1) [15–18] built by Space Applications Centre, launched on 26th April, 2012, has

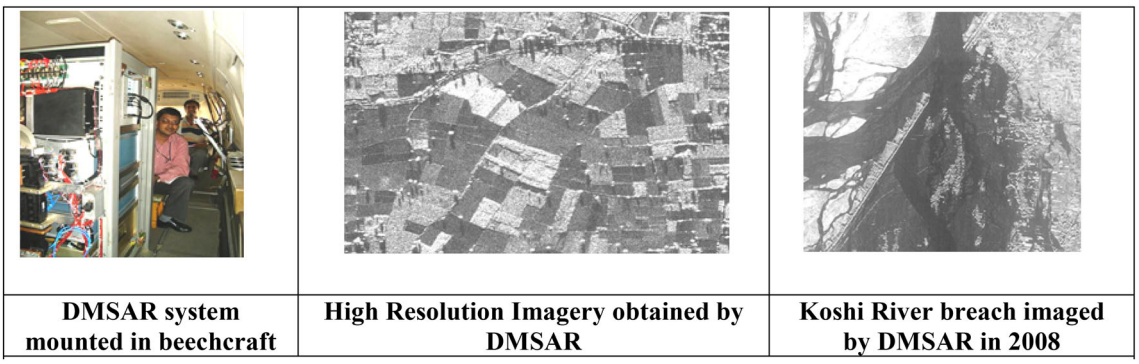
DMSAR system mounted in beechcraft
High Resolution Imagery obtained by DMSAR
Koshi River breach imaged by DMSAR in 2008

Fig. 10 DMSAR system and its applications for flood assessment in Koshi, DMSAR system mounted in beechcraft, High Resolution Imagery obtained by DMSAR, Koshi River breach imaged by DMSAR in 2008

been extensively used by Indian and international users for various applications like agriculture, forestry, oceanography geology, cryosphere, disaster management support, land-use, etc.

RISAT-1 SAR (Fig. 11) is operated in the following basic imaging modes:

- *Fine resolution stripmap mode-1 (FRS-1)* It is based on conventional mode of SAR Stripmap imaging, providing 25 km swath (25 km) with 3-meter resolution.
- *Coarse resolution scan SAR mode (CRS)* This 12-beam ScanSAR mode provides 223 km swath with a resolution of 50 m.
- *Medium resolution scan SAR mode (MRS)* This is a 6-beam ScanSAR mode, similar to the CRS mode, providing a resolution of 25 m over a swath of 115 km.
- *Fine resolution stripmap mode-2 (FRS-2)* This mode has quad polarization capability. Philosophically, this mode is a hybrid stripmap and scanSAR.
- *High resolution sliding spotlight mode (HRS)* In the sliding spotlight mode, the antenna beam is oriented continuously to illuminate a particular 10 km × 100 km sliding spot on the ground, which can be imaged with 1 m resolution.
- *Circular polarimetric modes (C-HRS, C-FRS-1, C-FRS-2, CMRS, C-CRS)* All the modes mentioned above can be operated in hybrid-circular polarization.

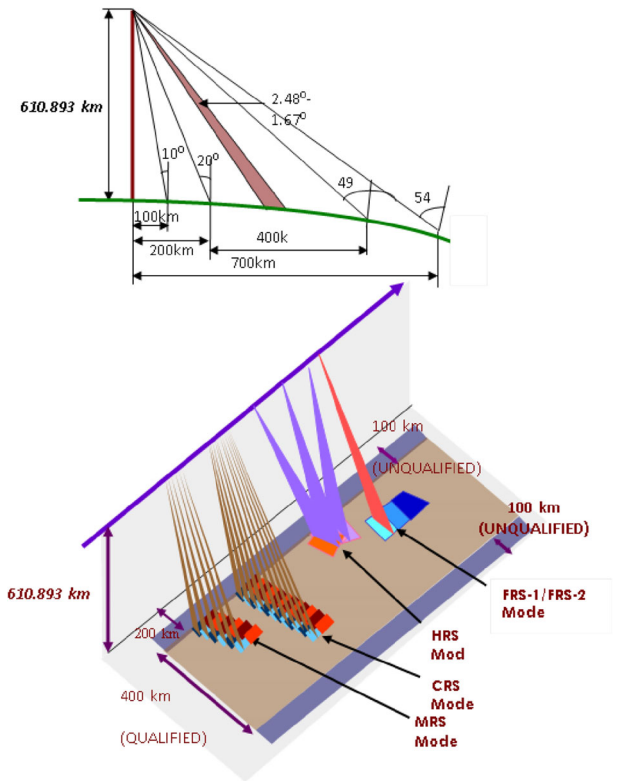

Fig. 11 RISAT imaging modes

There are several unique features of RISAT and the entire set of technologies associated with the payload is indigenous. RISAT-1 is the only C-band SAR in the world that is capable of giving 1 m resolution over 10 km x 100 km spot. It is the first SAR in the world with Hybrid polarimetry, which overcomes the constraint of restricted imaging below 35° incidence angle and allows RISAT-1 to operate at incidence angles as low as 12°. This feature helps the system develop new remote sensing application in soil moisture, glacier studies and better imaging in hilly regions.

RISAT-1 SAR images/data products are disseminated and utilized by the identified users on an operational basis mainly for Agriculture, Disaster Management and other ancillary applications related to oceanography, urban mapping, forest cover, etc. Hybrid Polarimetric SAR image generation from RISAT-1 SAR data is the other major capability utilized by interested scientists and researchers. Antrix, India has also entered into a major contract with M/s. Kongsberg Satellite Services (Ksat), Norway for RISAT-1 SAR direct data reception and SAR image generation at its Svalbard and Tromso stations, thereby confirming the good quality and international acceptability of RISAT-1 SAR data.

Apart from design and development of an active antenna based SAR system, the major achievement of RISAT project is extensive industrial partnership in developing critical technological elements needed for payload. This involved not only capacity building for production of space qualified hardware in the industry but also extensive qualification of production processes and training and sensitization of personnel involved. The TR module, along with all the MMICs associated with it, are designed and produced in India itself. Miniaturized pulsed EPC for powering TR module, featuring three different HMCs and planar transformer, has been a feat of Indian industry. Printed antenna aperture has been designed in ISRO and produced by Industry. The ASIC meant for controlling active array antenna elements, has been designed in-house.

4.5.3 ScatSAT-1

OSCAT, during its life time has demonstrated the importance and significance of the ocean wind vector data in weather modeling and prediction and laid the ground for continuation of the global ocean surface wind vector data acquisition. Based on this experience, SCATSAT-1 (Scatterometer Satellite) mission was planned as a dedicated mission to continue the global ocean wind vector data acquisition started by the OSCAT. SCATSAT-1 is configured on Indian Mini Satellite (IMS-2) Spacecraft bus of ISRO. Scatsat-1 is a Ku-band pencil-beam Scatterometer radar-only payload mission, has been launched in

September 2016. The Scatterometer instrument onboard SCATSAT-1 is similar to the OSCAT flown onboard OCEANSAT-2.

Retention of major system levels specifications (altitude, scan geometry, look and incidence angles) has facilitated fast realization through the usage of hardware procured or designed for OSCAT. RF designs viz., Frequency Generator, TWTA, Front-End Switch Assembly (FESA), Receiver subsystem, have been retained while digital subsystem has been miniaturized by combining various functionalities like baseband chirp generation, radar Controller and Data acquisition and onboard processing into one subsystem. Major changes have been introduced to improve the overall instrument reliability factor through cross patching of the critical subsystems. Though the OSCAT has been designed primarily for capturing ocean surface wind vector data, it has been found that the scatterometry data has wide applications in sea ice and polar ice studies as demonstrated by both QuikScat and OSCAT.

4.5.4 Ground Penetration Radar

The design and development of a miniaturized ground penetration radar, operating at 250-750 MHz, has been taken up by SAC as a proof-of-concept prototype for geodetic applications on earth as well as future lunar and planetary missions, to derive information about land profile, geology and other potential subsurface resources. The frequency-stepping P-Band instrument uses a bow-tie antenna and is realized in a compact 8.4 W, 10 kg frame that is easy to use. The instrument makes use of miniature ruggedized (IP67 compliant) SSR of 64 MB (extendable to 512 MB) with UART recording interface and USB data-retrieval interface, specifically for GPR operations. Low-cost instrument has been realized which is $\sim$ 20 times cheaper than commercial equivalent. Indian market is presently procuring GPRs from only foreign suppliers. Hence, this instrument presents a viable indigenous alternative, and is being offered for Technology Transfer.

This GPR has been a prime instrument for Antarctica snow studies (Indian Scientific Expedition to Antarctica, ISEA) over the past three years; the fourth expedition with this GPR is currently in progress. Snow and Ice profiles up to 14 m depth have been recorded at Antarctica (Fig. 12).

4.5.5 Follow-On Mission: RISAT-1A

To provide continuity of RISAT-1 mission, a follow-on mission called RISAT-1A has been already approved for launch by 2018-19 timeframe. Keeping in view the long lead times associated with the development of active-array electronics and other elements (like, antenna structure, spacecraft interfaces), no major changes have been planned in RISAT-1A configuration. Therefore, the system specifications of RISAT-1A are primarily the same as that of RISAT-1.

The improvements in RISAT-1A include configuration of full-polarimetric mode in lieu of quad-pol mode of RISAT-1 (termed Fine Resolution Stripmap-2, FRS-2; which basically operates with alternate bursts of H and V transmit pulses). Though the full polarimetric mode calls for high PRF (due to alternate H & V pulses) and compromises on swath, it allows extraction of the complete 4×4 Stokes' matrix and is therefore, considered to be the gold-standard for polarimetric observations. Due to these factors, the full-polarimetric mode is an important inclusion in the RISAT-1A configuration. Hybrid polarimetry available with all the resolution modes of RISAT-1 will be retained in RISAT-1A as well. As a result, both the forms of polarimetry (hybrid and full-pol) will be available in RISAT-1A.

RISAT-1A will operate from a sun synchronous orbit at a nominal altitude of 536 km, same as that for RISAT-1. It will image from nominal 100 to 700 km off-nadir distance and corresponding look angles will vary from 10.5° to 50.6°.

4.5.6 RISAT-2A

RISAT-2A Active antenna based Synthetic Aperture Radar development is initiated with the objective of providing continuity to RISAT-2 mission requirements. RISAT-2 satellite was launched in April 2009 with mission life of 5 years. The SAR will operate in X-band with centre frequency 9.6 GHz with Single/Dual/Circular Polarization capability. It will offer multimode operation with high spatial resolution. The SAR will have a high resolution mode with spatial resolution of less than 0.4 m.

All the modes (StripMap, Spot, Fine Spot and Mosaic) are available in single polarization (HH/VV), dual polarization (HH + HV, VV + VH) and hybrid-circular polarimetry (transmit circular, receive linear). Swath coverage of 200 km to 650 km will be achieved by roll-tilting of the satellite.

In order to provide greater flexibility in the selection of the look angles for different applications and to increase the effective repeatability, a region on the ground may be accessed by different look angles ranging from 23.4° to 52.8° corresponding to off-nadir distances of 200 km and 650 km, respectively. This look angle variation is implemented by roll-tilting the satellite.

Electronic beam scanning of $\pm$ 2° in elevation direction and $\pm$ 2° in azimuth direction is planned. SAR will operate with basic elevation beam limited swath of 6–10 km, over a total ground distance of 450 km, starting from an off nadir distance of 200 km and up to 650 km.

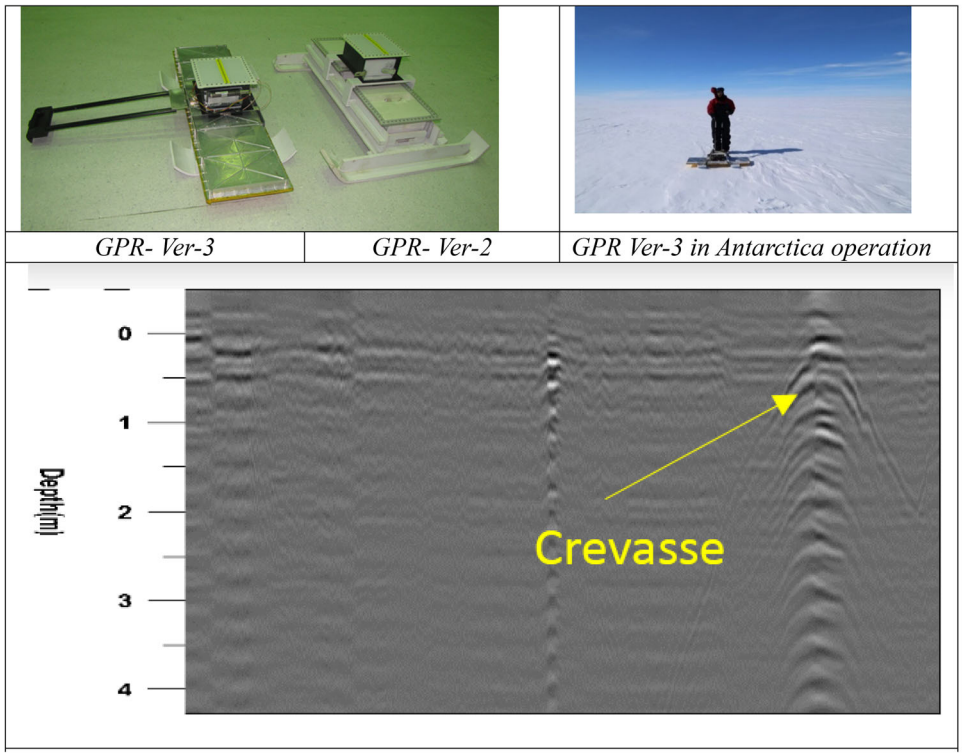

Fig. 12 GPRs and crevasse observed from Antarctica

4.5.7 X-band MiniSAR

X-Band Miniaturized Synthetic Aperture Radar is developed with the objective of high spatial resolution imaging from an airborne platform. The SAR can operate in X-band, Single/Dual/Circular Polarization, with high spatial resolution. The system design is made such that it can accommodate altitude variation of 3 km to 10 km with onboard data storage. System can be fit in small aircrafts as it has small size and low weight.

4.5.8 L &S Airborne SAR

ISRO in collaboration with NASA & JPL is developing a Dual Frequency Sweep SAR (DFSS) in L and S bands. As part of this, Space Applications Centre (SAC), ISRO is realizing the S-SAR and Jet Propulsion Laboratory (JPL), NASA is developing the L-band SAR. In this process, a number of new technologies in digital and RF domains are being developed at SAC. As a pre-cursor to the spaceborne SAR development, an airborne SAR in L& S band is being planned. For the airborne version, both L & S band SARs will be developed simultaneously by SAC itself, adhering to system design aspects of NISAR to the maximum extent possible. The sensor being developed is aimed to be operated in a Beech craft, currently available with NRSC, Hyderabad. The system is being designed to be operated at an altitude of 8 km with a platform velocity of 120 m/s. The centre frequencies are maintained at 3200 MHz for S-band SAR and 1250 MHz for L-band SAR, with bandwidth options of 25, 50 and 75 MHz, as in the case of NISAR. The sensor is being designed to operate in all the polarisation modes, viz. single, dual, compact, quasi-quad and full polarimetry.

4.5.9 L-Band SAR Satellite

Presently plans are afoot to build an L-band SAR as successor of RISAT (Fig. 13). Presently the pay load is in drawing board. This SAR will have scan SAR modes matching with RISAT. It will have stripmap mode of resolution 5 m and swath of 60 m. The interesting addition will be electronically steered spotlight mode providing 2.5 m resolution over 340 × 40 km spot. Compared to RISAT, it will have additional linear polarimetry mode apart from Hybrid polarimetry.

Like RISAT, the antenna will be based on active array technology to provide electronic steering in elevation and limited electronic steering in azimuth to support spotlight mode. The antenna size will be 10mx3 m, weighing 600 kg and the satellite is being planned for launch by PSLV.

L-band SAR pay load will also carry a demonstration model of Real Time Processor, for the first time, for processing the SAR raw data on the fly.

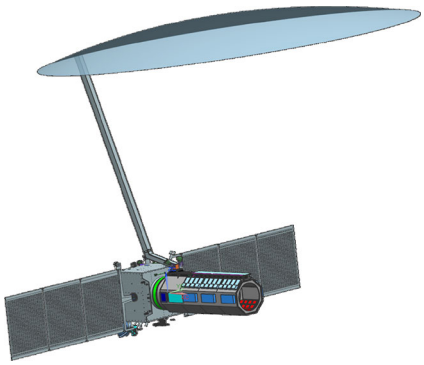

Fig. 13 L-Band SAR imaging configuration

4.5.10 NISAR

NASA/JPL and ISRO have undertaken a collaborative programme for the joint development and launch of dual band NISAR science mission, based on JPL's patented SweepSAR concept, which helps achieve wider swath without compromising resolution (Fig. 14). NISAR will be a unique radar imaging satellite mission carrying together, JPL/NASA's L-band SweepSAR and ISRO's S-band SweepSAR. It will support 5-10 m resolution over $>$ 225 km swath. The 12 m single reflector will serve both L- and S-band SweepSAR and will consist of 24 S-Band TR Module pairs for dual polarization operation. Payload level Baseline Design has been finalized and proof-of-the-concept development activities are underway related to various constituents like S-Band TR Integrated Module (TRiM) and RF Baseband & Digital hardware.

NISAR is optimized for studying hazards and global environmental change using advanced radar imaging that will provide an unprecedented, detailed view of Earth. The satellite is designed to observe and take measurements of the planet's most complex processes, including ecosystem disturbances, ice-sheet collapse, and natural hazards such as earthquakes, tsunamis, volcanoes and landslides. Scheduled to be launched in 2020, the mission will also monitor the country's agricultural biomass, snow and glacier studies in the Himalayas.

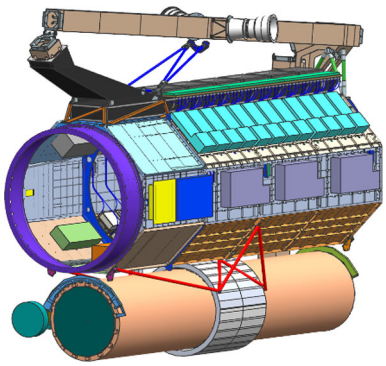

Fig. 14 Schematic of NISAR payload

5 Terahertz Telecscope

The vision of the Terahertz technology development program is to bridge the so-called Terahertz "technology" gap that exists between the technologies at microwave and at infra-red and visible ends of the electromagnetic spectrum. The Terahertz gap spans over a large frequency range from mm-wave (up to 300 GHz) to sub-millimeter wave (300–750 GHz) and further to far infrared (25–350 μm). The technology is entirely different as one moves from one frequency regime to another— rom Schottky Barrier diodes to Superconductor-Insulator-Superconductor (SIS) to Bolometers and their associated stringent cooling requirements. Globally, astronomical observation has been the prime science driver for THz technology development for studying the evolution of the universe by spectroscopic and continuum observations in the ISM, the circumstellar discs, giant molecular clouds, proto-planetary discs, asteroids, and Young Stellar Objects of galaxies at different red shifts.

Continuing ISRO's thrust for building and indigenizing state-of-the-art technologies for various microwave/optical payloads, for realization of a multi-frequency mm-wave/-sub-millimeter wave sensor covering frequency range up to 300 GHz, various critical technologies will be indigenously developed at SAC.

6 Future Scenarios

Currently available data from various EO systems are operationally used in many national level resource monitoring programs but still many gap areas exists in observations as well applications and it need to be addressed in future. Need of high spatial resolution imaging is growing for infrastructure development including risk mapping and providing real time support for natural and human induced disasters. Multi crop inventory and detection of crop disease and pest require high revisit measurements at high spatial resolution with hyper spectral technology. The cartographic and urban/rural planning is an important thrust area. The Cartosat data has immense potential in this field. There is further need for high resolution mapping for preparation of rural development plans and creation of land information system, land parcel mapping at 1: 1000 to 1: 4000 scale cartographic maps.

It is proposed that Cartographic series be continued with launch of a very high spatial resolution camera on board Cartosat-3. LISS_III sensor would be modified into LISS-

III-WS (Wide Swath) having swath around 925 km and revisit capability better than AWiFS in future Resourcesat-3/3A mission. New configuration in Resourcesat-3/3A will help in overcoming spatial resolution limitation of AWiFS. Resourcesat-3S, with multi-view panchromatic stereoscopic capability having high spatial resolution of 1.25 m will facilitate generation of fused products of great utility.

Vegetation stress, disease and pest detection using hyper spectral techniques such as red edge shift and mineral targeting are some of the important applications, which would require hyperspectral spectrometer on board IRS satellites on operational basis.

The cloud cover remains a major hurdle in optical remote sensing during monsoon season. Imaging RADAR applications are being served through RISAT-1 satellite. The C- band SAR sensor onboard the RISAT-1 satellite is found to be very useful for resource monitoring and disaster monitoring. Follow on mission with features similar to RISAT-1 (C-band and multi-polarization) with multi resolution capability is planned for service continuity. The L-band SAR is suggested on RISAT-3 mission for applications supporting soil moisture, crop and forest type discrimination. In addition, RISAT-1A (C band) and RISAT-2A(X band) are planned to meet needs of monitoring disaster situations. NISAR (L and S band), the NASA ISRO joint mission is optimized for studying hazards and global environmental change using advanced radar imaging that will provide an unprecedented, detailed view of Earth. Geostationary orbit provides constant surveillance, and 1 km imaging capability in visible and Near Infra red region already exists on INSAT 3A and additional channels available on INSAT-3D. Beyond Resourcesat-2/2A, high repetivity sensor with moderate spatial resolution would be continued on geostationary platform as a GISAT. This will provide multiple/day acquisition capability and overcome all limitations posed on current AWiFS data availability. Terahertz Telescope will start a new phase in our understanding of universe.

The Indian Remote Sensing satellite series from IRS-1A to IRS-P6/IRS-P5/Cartosat-2/2A/2B/2C/2D, Resourcesat-2/2A, RISAT-1/2, Oceansat-2, SCATSAT-1, Megha Tropiques, SARAL and sensors onboard-INSAT series of satellites like INSAT-3D/3DR have established space technology for operational applications related to areas of societal benefits. The missions planned in near future viz. Cartosat-3/3A, Oceansat-3/3A, INSAT-3DS*, GISAT-1, RISAT-1A/2A, NISAR shall enhance utility of EO data in meeting needs of societal benefit areas. Institutional framework for ensuring utilization of EO data is in place. Capacity building at different levels including decision makers is organized. Indian EO data is available to global users through the international ground stations set up and capacity building is extended to countries in the Asia–Pacific region. Continuity of EO missions with enhanced capability has been ensured. Road ahead for the EO programme has been visualized. Thus, Indian Earth Observation Programme is complementing GEOSS and adding to the remote sensing infrastructure in the world

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